CAE 208 / MMAE 320: Thermodynamics

Fall 2023

September 5, 2023

Energy, energy transfer, and energy analysis (I)

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ANNOUNCEMENTS

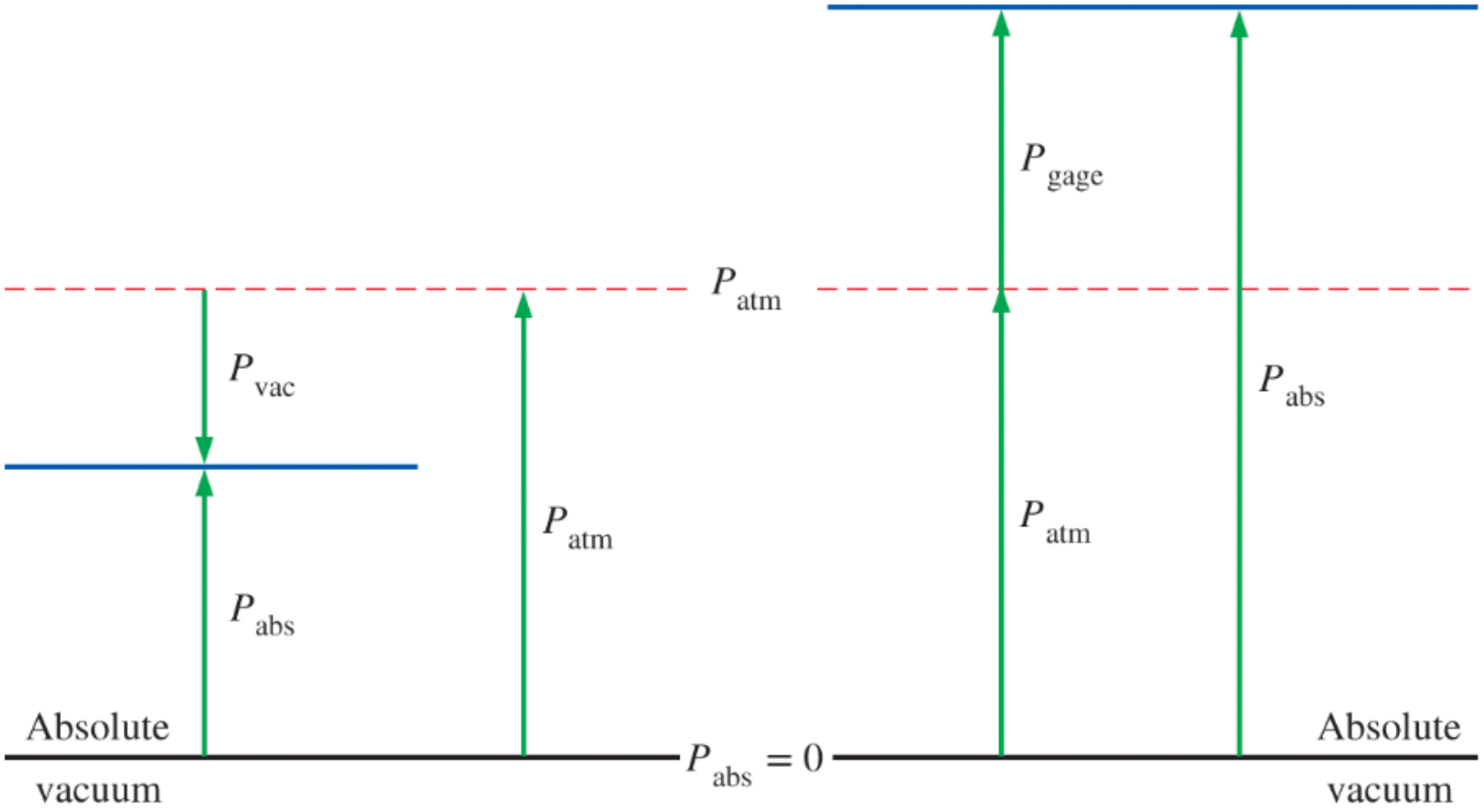
Announcement

Announcements

- Assignment 1 was graded, and the solution is posted
- Assignment 2 is posted (due this coming Thursday)
- We will have our first in class quiz today

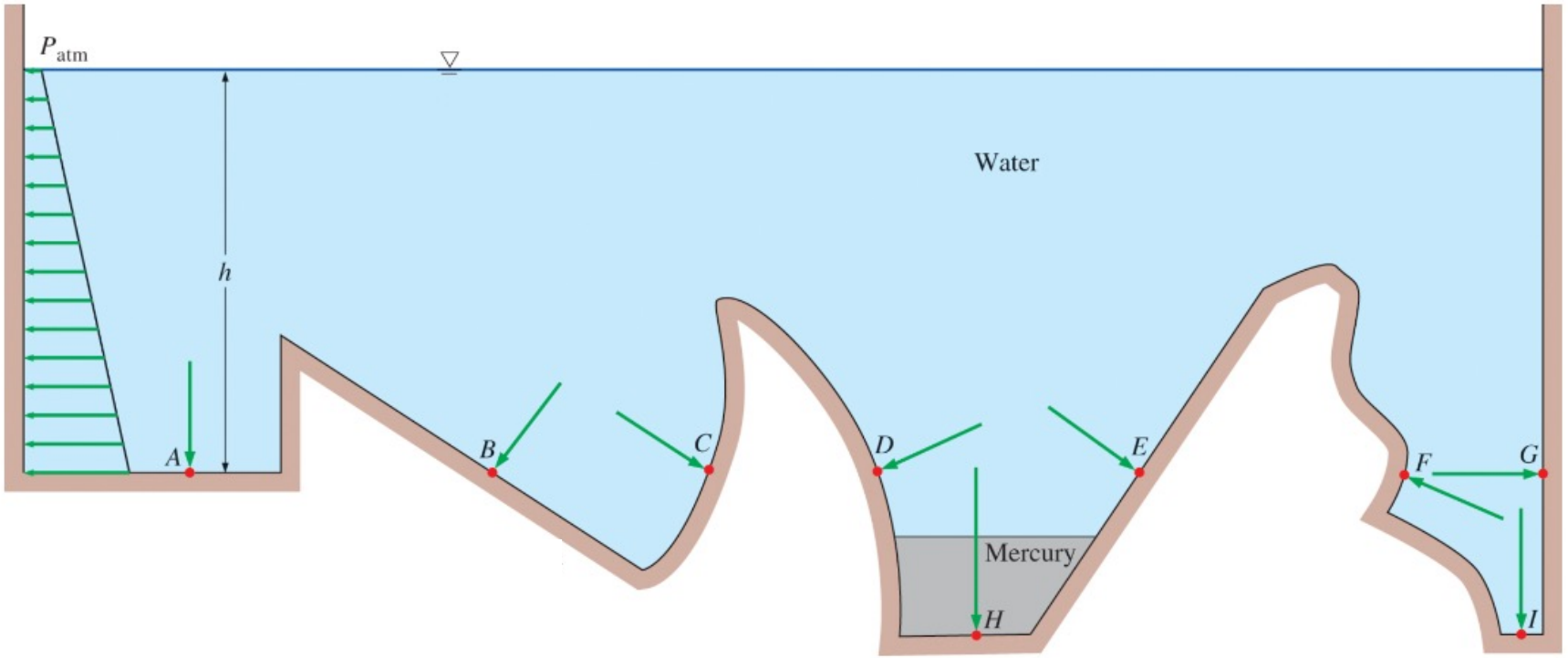
RECAP

Recap


P_{gage}
P_{atm}
P_{vac}
P_{abs}
P_{atm}
P_{atm}
P_{abs}
Absolute
vacuum
$P_{abs} = 0$
Absolute
vacuum

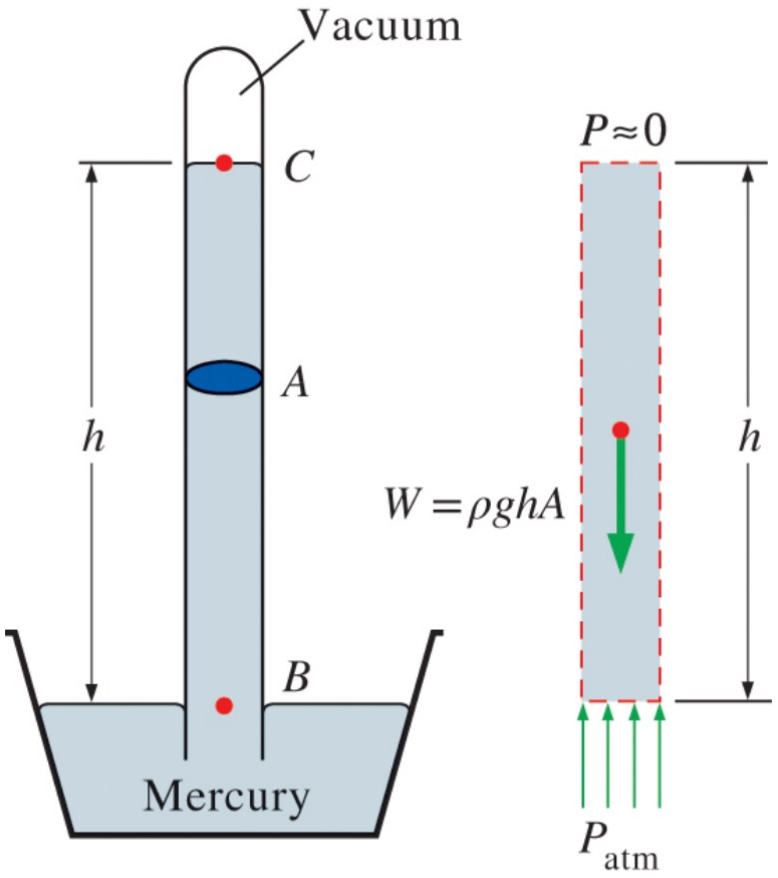
Recap

- We learned about the pressure distribution



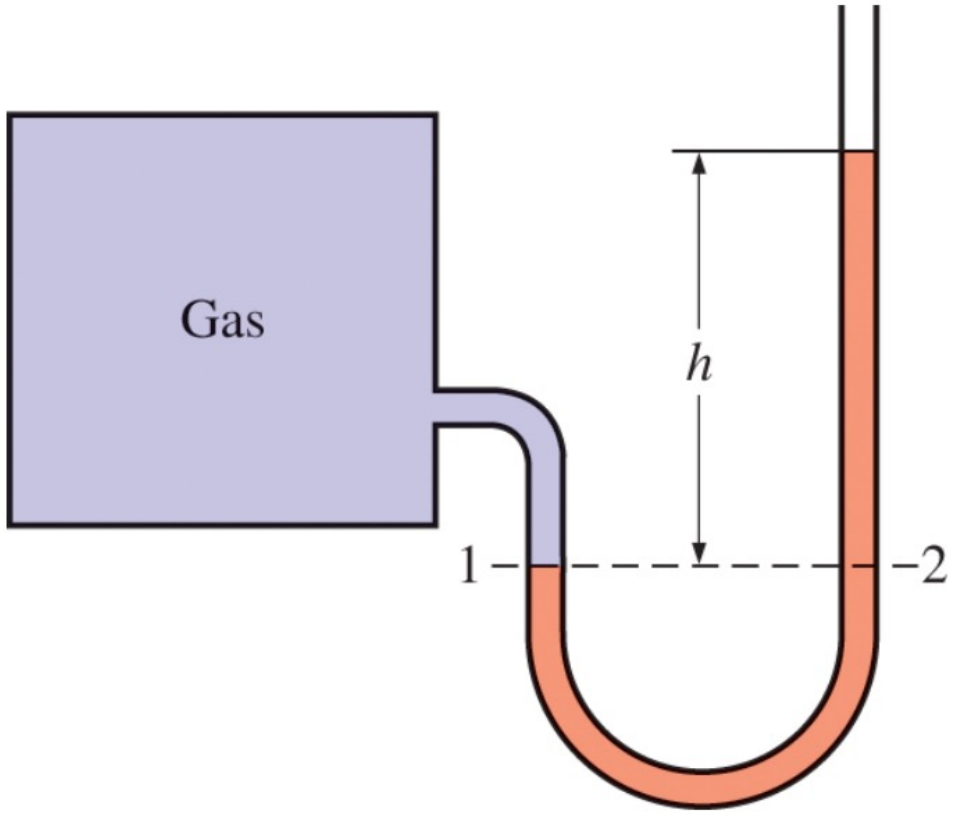
Recap

- Atmospheric pressure is measured by a device called a barometer (atmospheric pressure is known as barometric pressure)



Recap

- Manometer



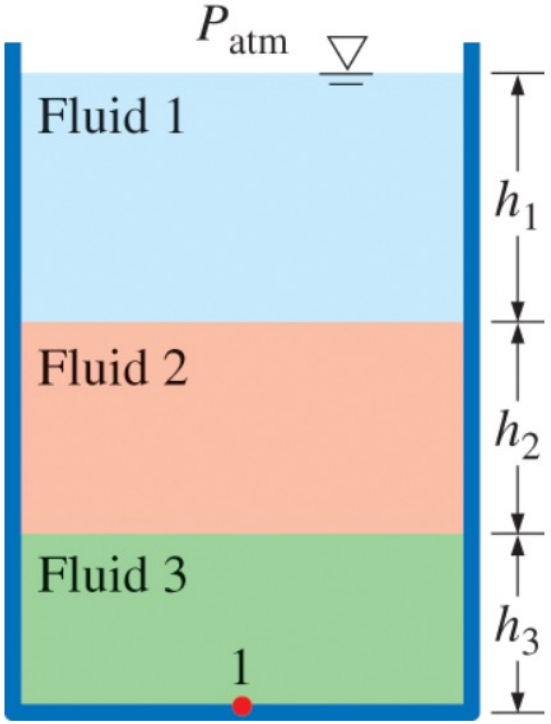
QUIZ

Quiz Solution

MANOMETER

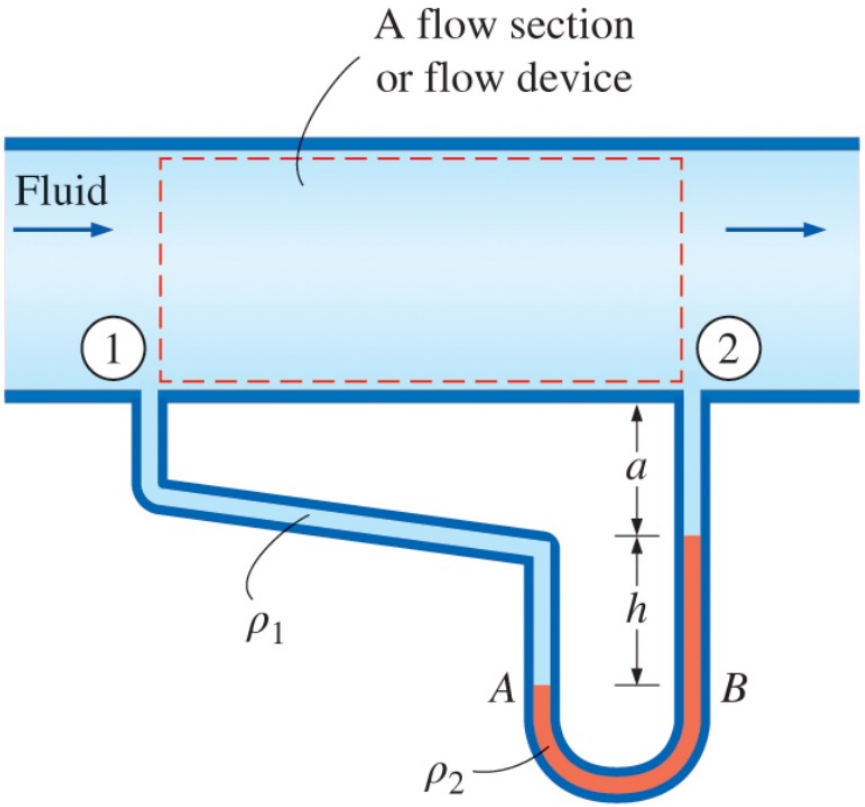
Manometer

- Special manometer designs
  - ❑ Inclined manometer
  - ❑ Using the extension of Pascal's law



Manometer

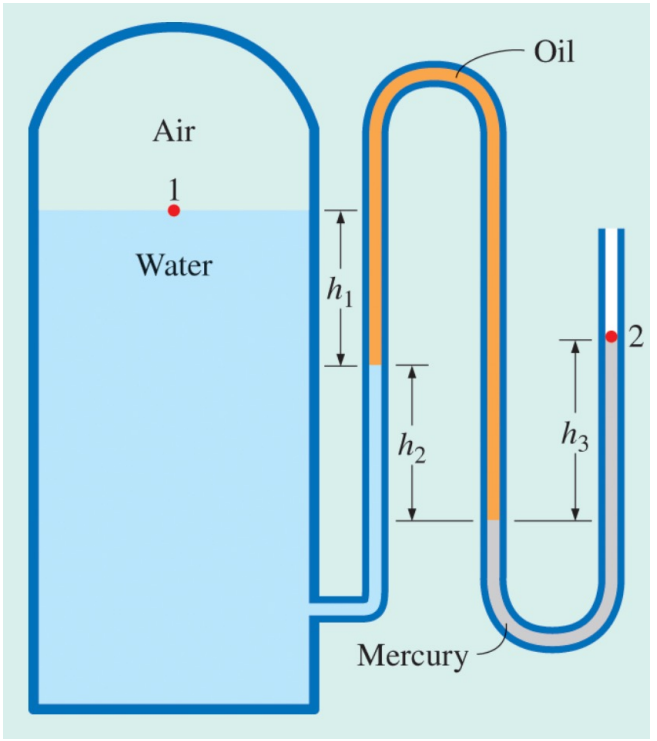
- Special manometer designs
  - ❑ Measure pressure drop in a duct due to other equipment



CLASS ACTIVITY

Class Activity

- Water in a tank is pressurized by air and the pressure is measured by a multifluid manometer. The tank location is on a mountain and the altitude of 140 m where the atmospheric pressure is 85.6 kPa. Determine the air pressure in the tank is h_1 = 0.1 m, h_2=0.2 m, and h_3=0.35 m. The densities of water, oil, and mercury is 1,000 kg/m^3, 850 kg/m^3, and 13,600 kg/m^3, respectively.



Class Activity

- Solution

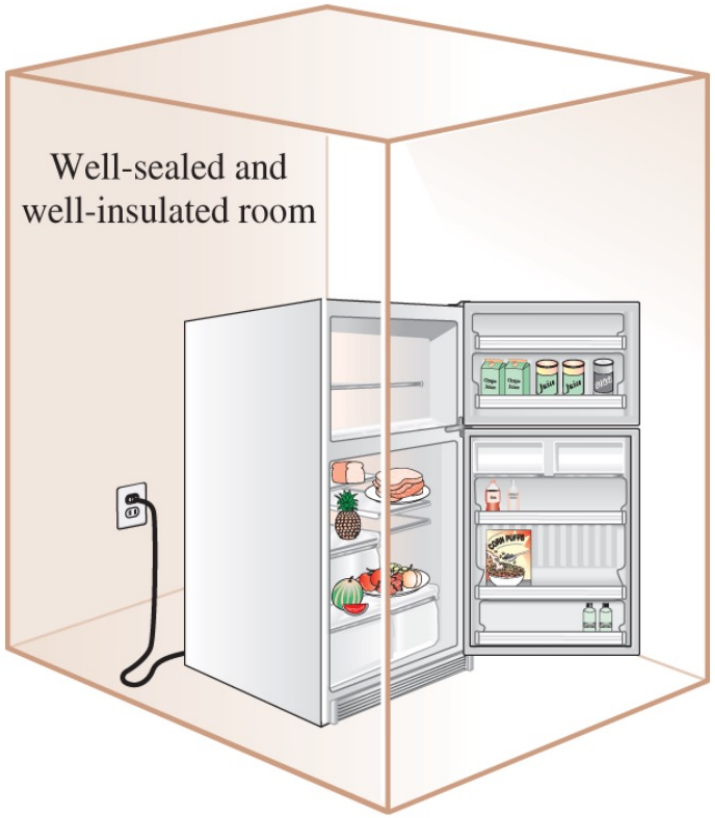
Extra Examples

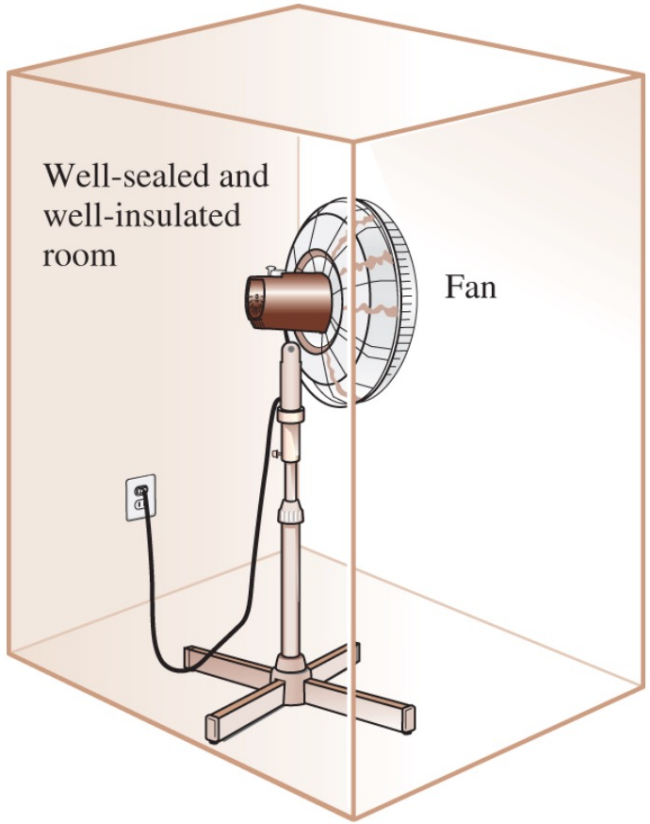
- Please see the last two examples in the last lecture

INTRODUCTION

Introduction

- What does happen to this room?





Introduction

- Energy is conserved during the process of operating the refrigerator placed in the room

Converted from electrical energy to equivalent amount of thermal energy stored in the room air

Introduction

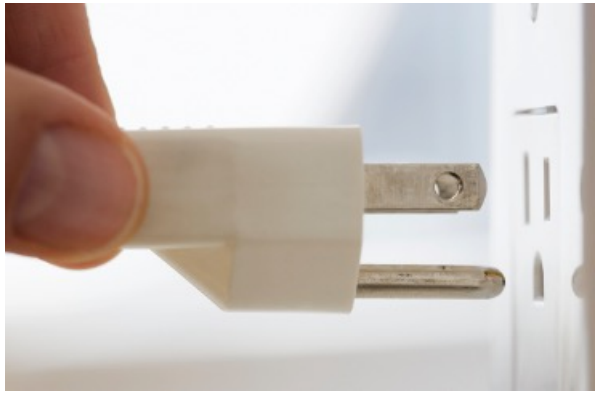
- Energy conservation means the conservation of the quality of energy not the quantity

Electricity is the highest quality of energy (e.g., can be always converted to thermal energy ”heat”)

FORMS OF ENERGY

Forms of Energy

- Energy can exist in numerous forms:
  - ❑ Thermal
  - ❑ Mechanical
  - ❑ Kinetic
  - ❑ Potential
  - ❑ Electric
  - ❑ Magnetic
  - ❑ Chemical
  - ❑ Nuclear



Forms of Energy

- Sum of all energy constitutes the total energy (E) of a system

$$e = \frac{E}{m} \qquad \left(\frac{\text{kJ}}{\text{kg}}\right)$$

Thermodynamics deals only with the change of the total energy

Total energy depends on the reference frame

Forms of Energy

- In thermodynamics, we consider the total energy of a system into two groups:

  - Macroscopic (forms of energy are those a system possess as a whole with respect to some outside reference frame – e.g., kinetic and potential energy)

  - Microscopic (forms of energy related to the molecular structure of a system and the degree of the molecular activity and they are independent of the outside reference frame – sum of all of them are named internal energy (U))

Forms of Energy

- Kinetic energy is related to motion and the influence of some external effects such as gravity, magnetism, electricity, and surface tension

$$KE = \frac{1}{2}mV^2 \quad (kJ)$$

$$ke = \frac{1}{2}V^2 \quad (kJ/kg)$$

Forms of Energy

- Potential energy is the energy that a system possesses as a result of its elevation in a gravitational field

$$PE = mgz \quad (kJ)$$

$$pe = gz \quad (kJ/kg)$$

Forms of Energy

- Total energy of a system in the absence of magnetic, electric, and surface tension effects is

$$E = U + KE + PE = U + m\frac{V^2}{2} + mgz \quad (kJ)$$

$$e = u + ke + pe = u + \frac{V^2}{2} + gz \quad (kJ/kg)$$

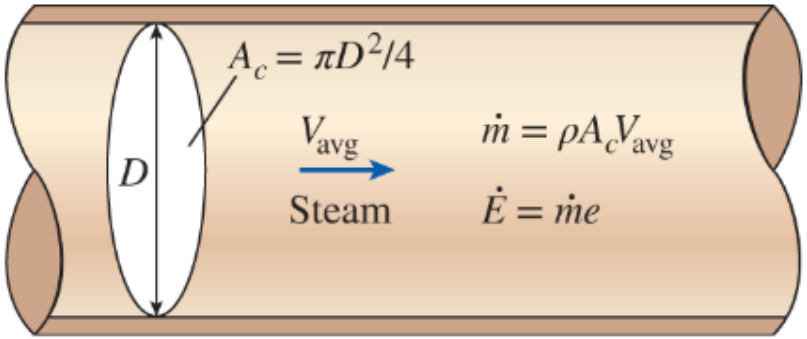
Forms of Energy

- Most closed systems remain stationary during a process and thus experience no change in their kinetic and potential energies

Forms of Energy

- Mass flow rates

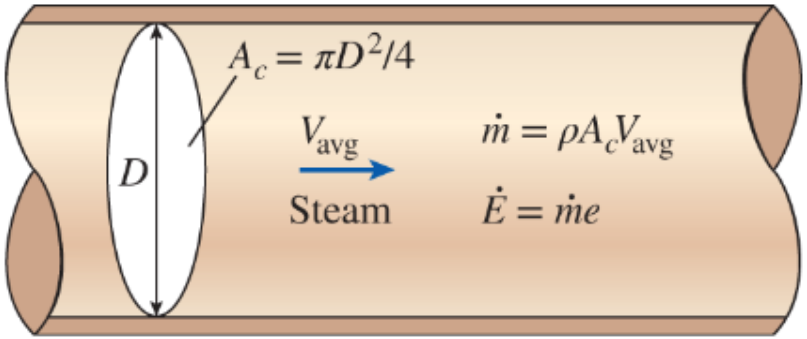
$$\dot{m} = \rho \dot{V} = \rho A_C V_{avg} \qquad (\frac{kg}{s})$$



Forms of Energy

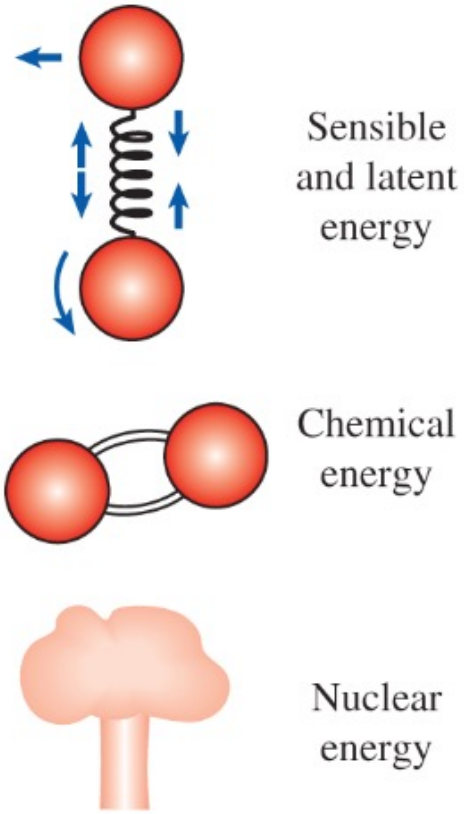
- Energy flow rates

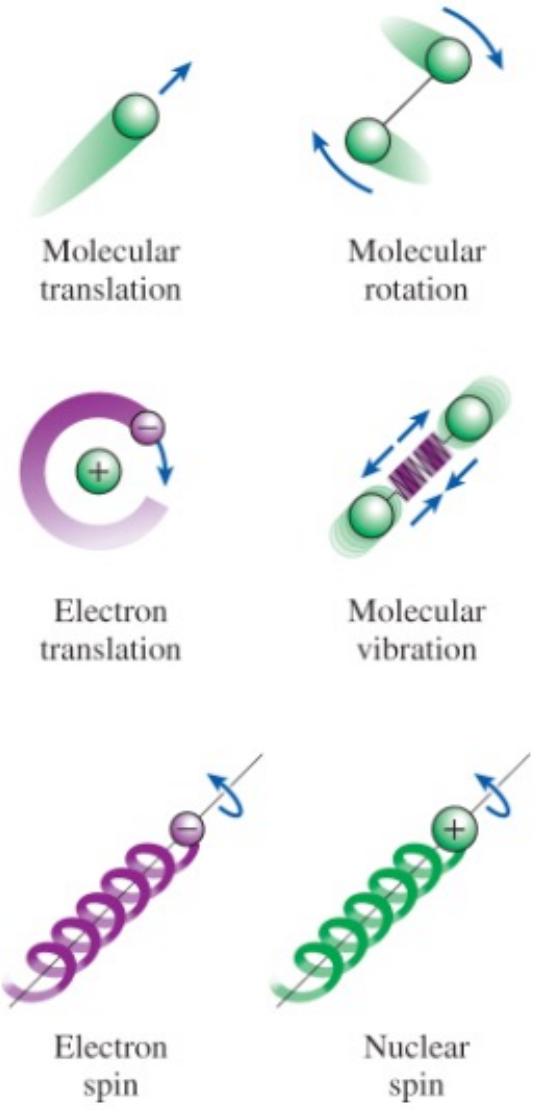
$$\dot{E} = \dot{m}e \qquad \left(\frac{kJ}{s}\right) \; or \; kW$$



Forms of Energy

- Internal energy





Forms of Energy

- Mechanical energy can be defined as the form of energy that can be converted to mechanical work completely and directly by an ideal mechanical device such as an ideal turbine

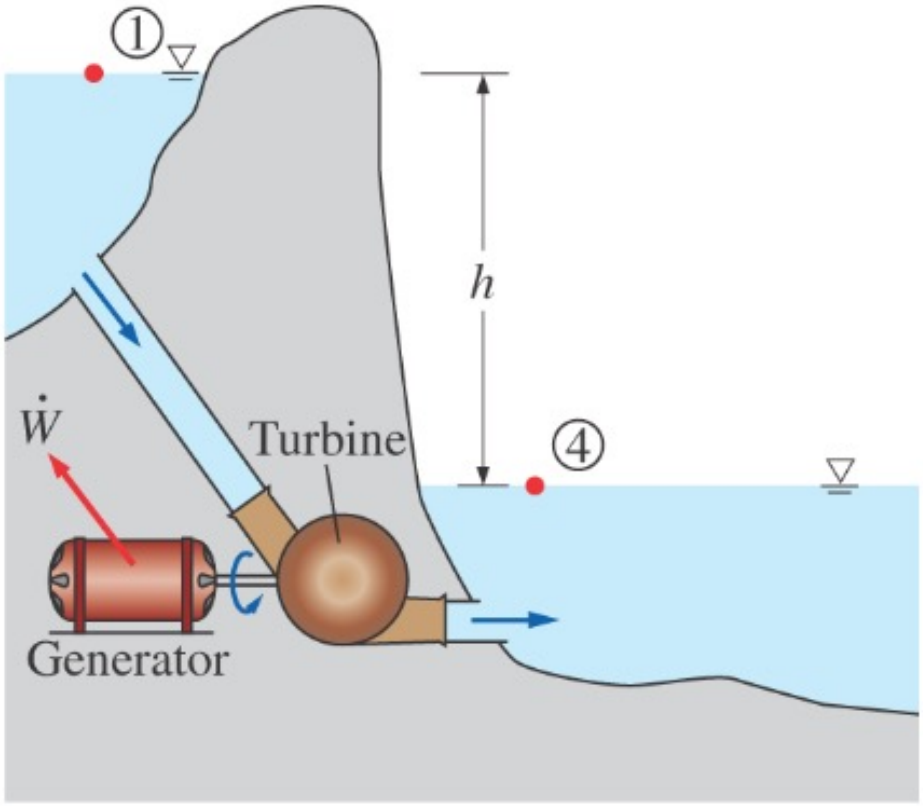
$$e_{mech} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

$$\dot{E}_{mech} = \dot{m}(\frac{P}{\rho} + \frac{V^2}{2} + gz)$$

$$\Delta\dot{E}_{mech} = \dot{m}\mathrm{e}$$

$\frac{P}{\rho}$: flow work (it is per unit mass)

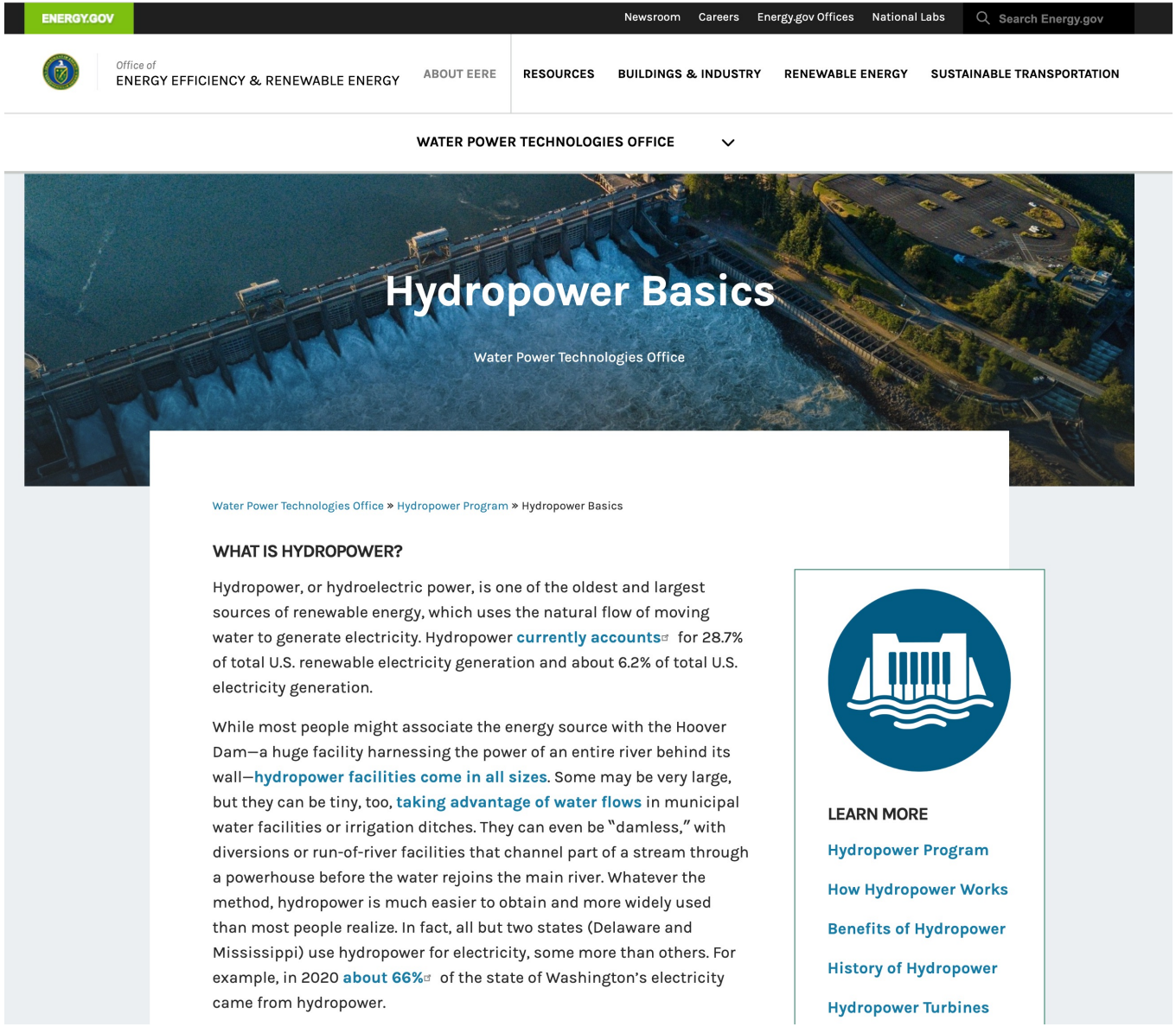
Forms of Energy



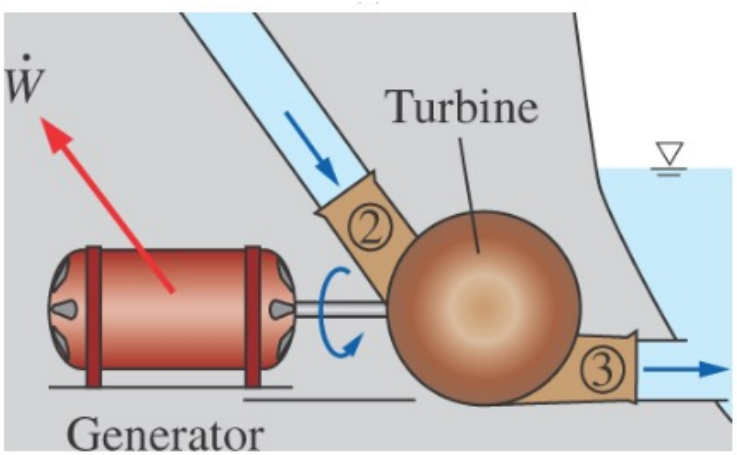
$$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}g(z_1 - z_4) = \dot{m}gh$$

since $P_1 \approx P_4 = P_{atm}$ and $V_1 = V_4 \approx 0$

Forms of Energy



Forms of Energy



$$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}\frac{P_2 - P_3}{\rho} = \dot{m}\frac{\Delta P}{\rho}$$

since $V_1 \approx V_3$ and $z_2 = z_3$

$\Delta e_{mech} > 0$ mechanical work supplied to the fluid

$\Delta e_{mech} < 0$ mechanical work extracted from the fluid

CLASS ACTIVITY

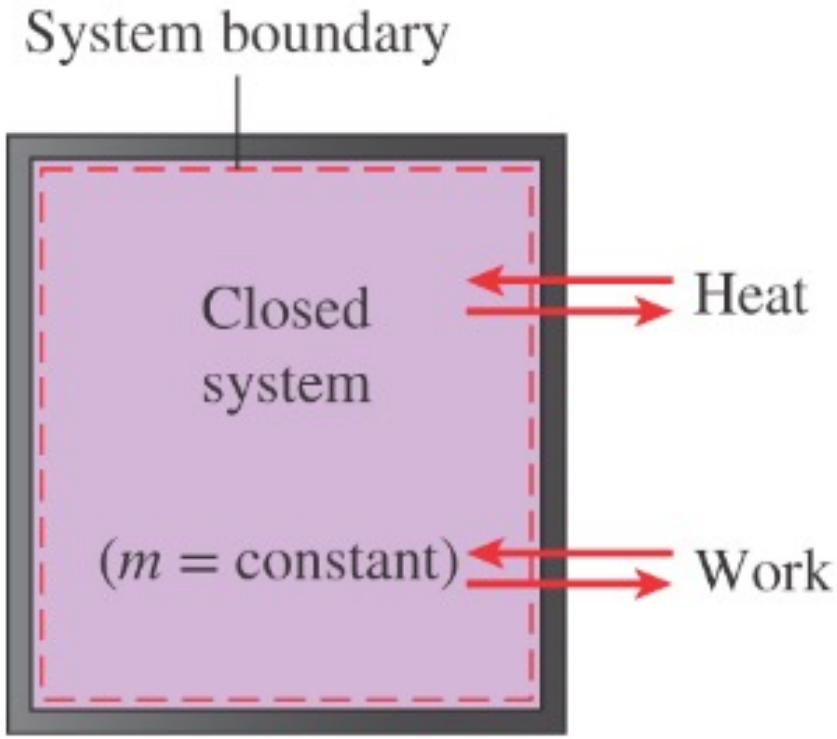
Class Activity

- A site evaluated for a wind farm is observed to have steady winds at a speed of 8.5 m/s. Determine the wind energy
  - ❑ Per unit mass
  - ❑ For a mass of 10 kg
  - ❑ For a flow rate of 1154 kg/s of air

ENERGY TRANSFER BY HEAT

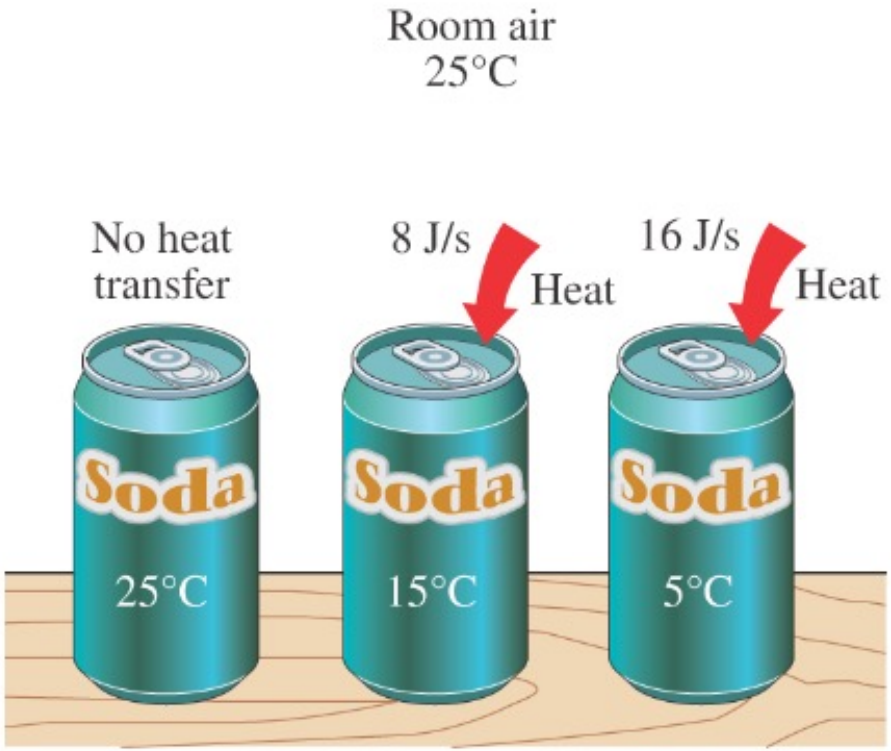
Energy Transfer by Heat

- Energy can cross the boundary of a closed system in two distinct forms:
  - ❑ Heat
  - ❑ Work



Energy Transfer by Heat

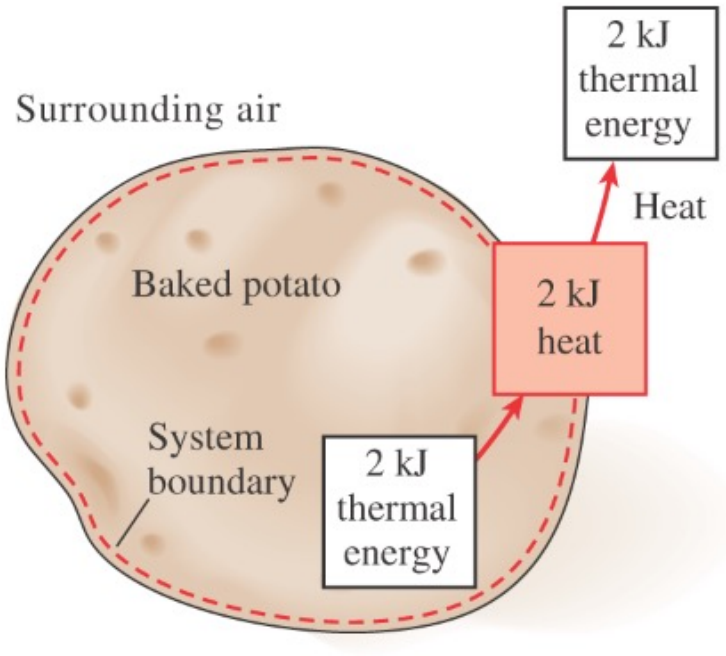
- Heat is defined as the form of energy that is transferred between two systems (or a system and its surrounding) by virtue of a temperature difference



Energy Transfer by Heat

- Energy is recognized as heat transfer only as it crosses the system boundary

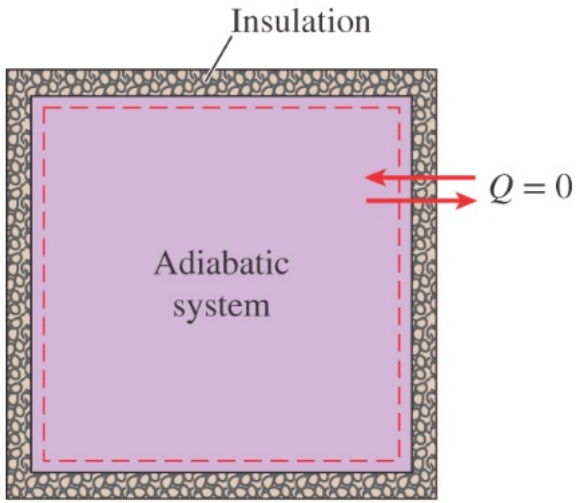
$$q = \frac{Q}{m} \quad \left(\frac{kJ}{kg}\right)$$



Q_{12}

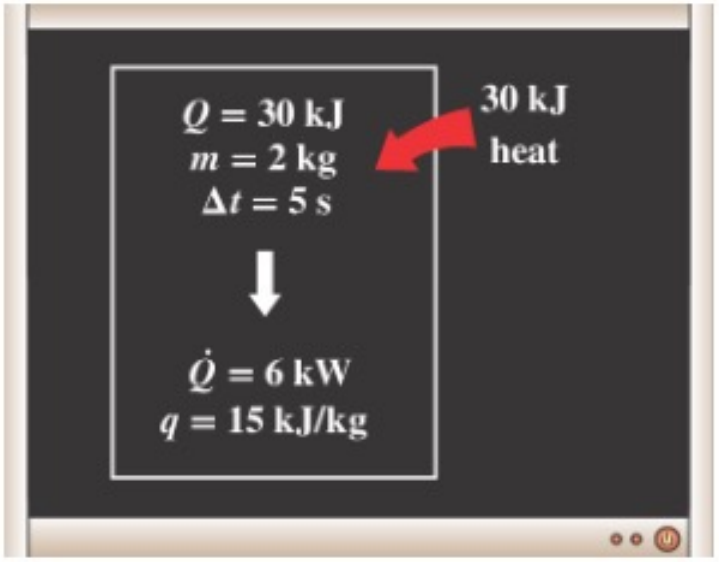
Energy Transfer by Heat

- A process during which there is no heat transfer is called an adiabatic process.
- Two ways for a system to be adiabatic:
  - ❑ The system is well insulated so that only a negligible amount of heat can pass through the boundary
  - ❑ Both the system and the surroundings are at the same temperature and therefore there is no driving force for heat transfer



Energy Transfer by Heat

- Let's look at the relationship between the heat and heat transfer



$$Q = \int_{t_1}^{t_2} \dot{Q}\,dt \qquad (kJ)$$

$$Q = \dot{Q}\Delta t$$

$$q = \frac{Q}{m} \qquad \left(\frac{kJ}{kg}\right)$$

ENERGY TRANSFER BY WORK

Energy Transfer by Work

- Work like heat is an energy interaction between a system and its surrounding

- Remember heat is associated with temperature difference

- Work is the energy transfer associated with a force acting through a distance (e.g., a rising piston, rotating shaft, electric wire crossing the system boundaries)

Energy Transfer by Work

- Work is a form of energy transferred like heat the energy units such as kJ

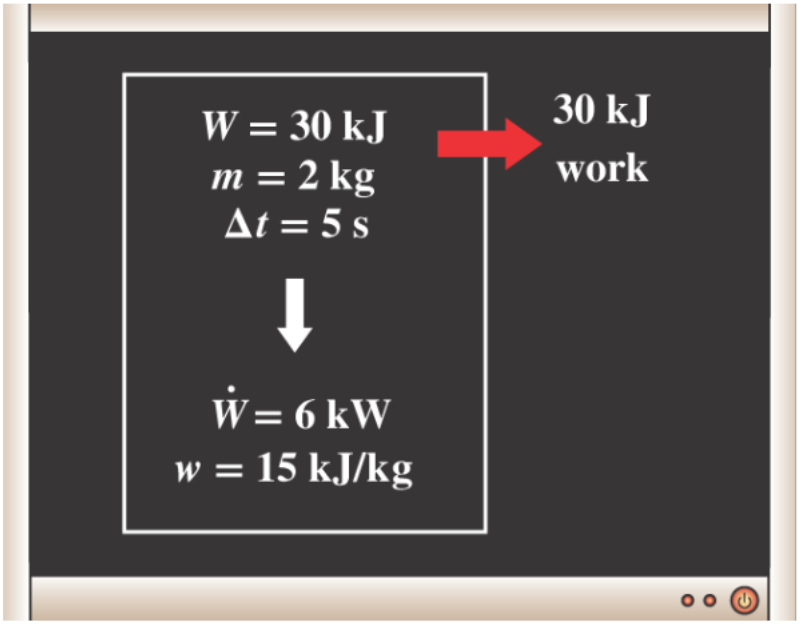
- Work done during a process between states 1 and 2 is donated by W_{12}

$$w = \frac{W}{m} \qquad (\frac{kJ}{kg})$$

Energy Transfer by Work

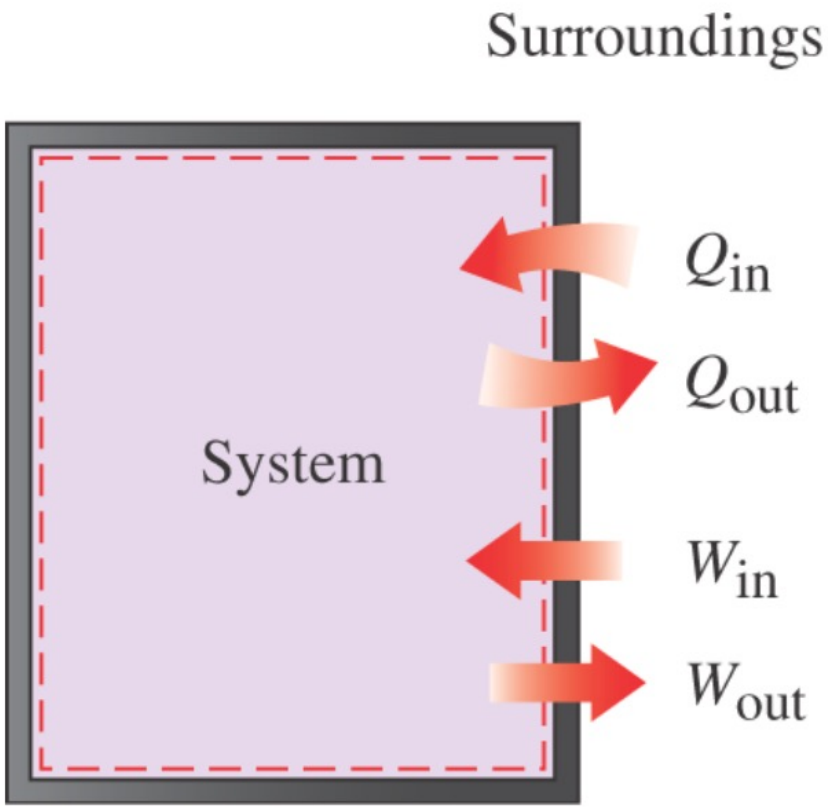
- Work done per unit time is called power and is donated with $\dot{W}$

- The unit of power is kJ/kg or kW



Energy Transfer by Work

- Heat and work are directional quantities



Energy Transfer by Work

- A quantity that is transferred to or from a system (e.g., heat and work) during an interaction is not a property since the amount of such a quantity depends on more than just the state of the system

Energy Transfer by Work

- Work and heat have similarities:
  - ❑ Both are recognized at the boundaries of a system as they cross the boundaries
  - ❑ Systems possess energy but not heat or work
  - ❑ Both are associated with a process not a state (unlike properties heat and work has not meaning at a state
  - ❑ Both are path functions (i.e., their magnitudes depend on the path followed during a process as well as the ends states)

Energy Transfer by Work

- Path functions have inexact differentials designated by the symbol δ (e.g., δW or δQ not $\mathrm{d}W$ or $\mathrm{d}Q$)

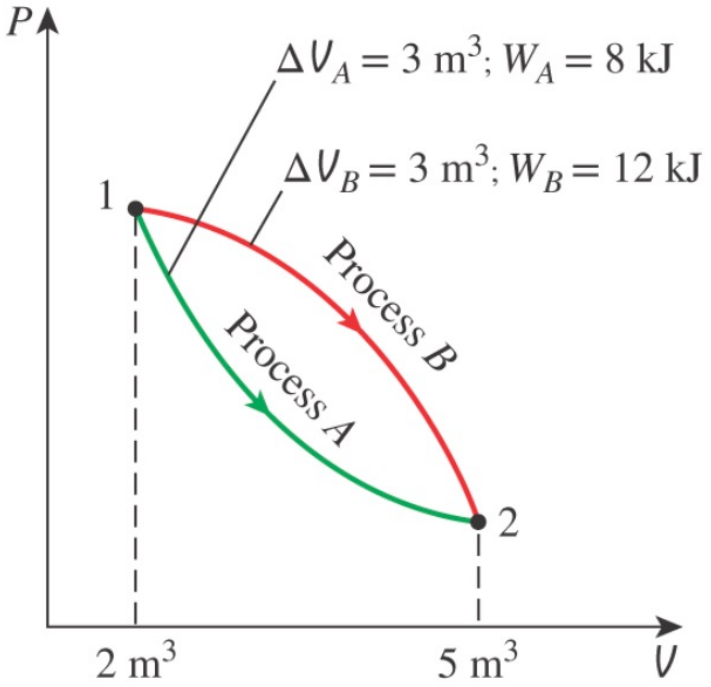
- Properties are point functions (i.e., they depend on the state only and not on how a system reaches the state), meaning they have exact differentials

$$\int_1^2 dV = V_2 - V_1 = \Delta V$$

$$\int_1^2 \delta W = W_{12}\ (not\ \Delta W)$$

Energy Transfer by Work

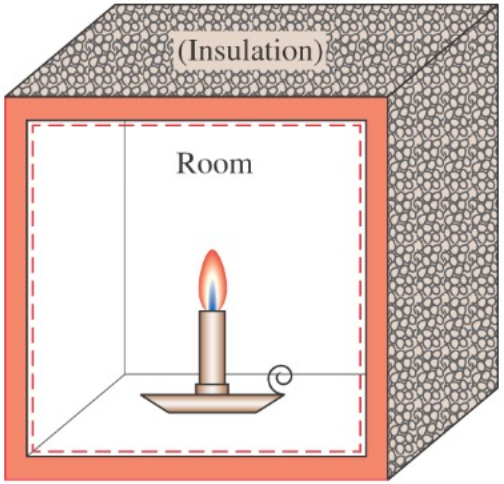
- Total work is obtained by following the process path and adding differential amounts of work (δW) done along the way
- The integral of δW is not $W_2 - W_1$ (Work is not a property!)
- Systems do not posses work at a state



CLASS ACTIVITY

Class Activity

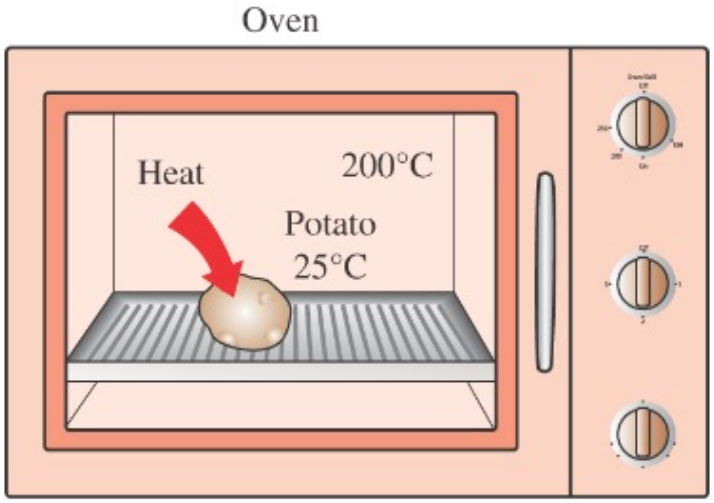
- A candle is burning in a well-insulated room. Taking the room (the air plus the candle) as the system, determine
  - ❑ If there is any heat transfer during the burning process
  - ❑ If there is any change in the internal energy of the system



CLASS ACTIVITY

Class Activity

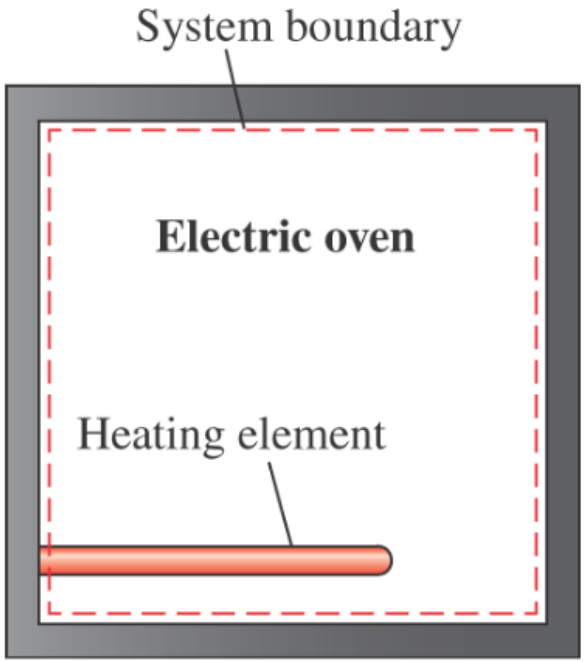
- A potato initially at room temperature (25 °C) is being baked in an oven that is maintained at 200 °C. Is there any heat transfer during this baking process.



CLASS ACTIVITY

Class Activity

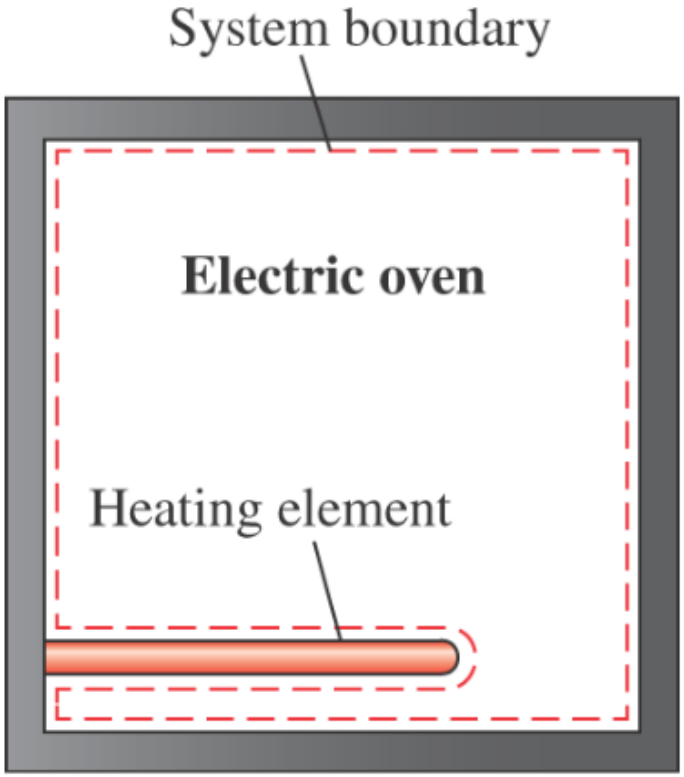
- A well-insulated electric oven is being heated through its heating element. If the entire oven, including the heating element is taken to be the system, determine whether there is a heat or work interaction.



CLASS ACTIVITY

Class Activity

- Answer the previous class activity is the air is considered without the heating element.



ELECTRICAL WORK

Electrical Work

- Electrical power is